

Search for massive rare particles with the SLIM experiment

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Abstract

The SLIM experiment is a large array of nuclear track detectors located at the Chacaltaya High Altitude Laboratory (5260 m a.s.l.). The preliminary results from the analysis of $\sim 383 \text{ m}^2$ exposed for 4.07 y are here reported. The detector is sensitive to Intermediate Mass Magnetic Monopoles, $10^5 < M_M < 10^{12} \text{ GeV}$, and to SQM nuggets and Q-balls, which are possible Dark Matter candidates.

1 Introduction

Grand Unified Theories (GUT) of the strong and electroweak interactions predict the existence of magnetic monopoles (MMs), produced in the early Universe at the end of the GUT epoch, with very large masses, $M_M > 10^{16} \text{ GeV}$. GUT poles in the cosmic radiation should be characterized by low velocity and relatively large energy losses [1]. At present the MACRO experiment has set the best limit on GUT MMs for $4 \cdot 10^{-5} < \beta < 0.5$ [2].

Intermediate Mass Monopoles (IMMs) [$10^5 \div 10^{12} \text{ GeV}$] could also be present in the cosmic radiation; they may have been produced in later phase transitions in the early Universe [3]. The recent interest in IMMs is also connected with the possibility that they could yield the highest energy cosmic rays [4]. IMMs may have relativistic velocities since they could be accelerated in one coherent domain of the galactic magnetic field. In this case one would have to look for downgoing fast ($\beta > 0.1$) heavily ionizing MMs.

Besides MMs, other massive particles have been hypothesized to exist in the cosmic radiation and to be components of the galactic cold dark matter: nuggets of Strange Quark Matter (SQM), called nuclearites when neutralized by captured electrons, and Q-balls. SQM consists of aggregates of u, d and s quarks (in approximately equal proportions) with slightly positive electric charge [5]. It was suggested that SQM may be the ground state of QCD. They should be stable for all baryon numbers in the range between ordinary heavy nuclei and neutron stars ($A \sim 10^{57}$). Nuclearite interaction with matter depend on their mass and size. In ref. [6] different mechanisms of energy loss and propagation in relation to their detectability with the SLIM apparatus are considered. In the absence of any candidate, SLIM will be able to rule out some of the hypothesized propagation mechanisms.

Q-balls are super-symmetric coherent states of squarks, sleptons and Higgs fields, predicted by minimal super-symmetric generalizations of the Standard Model [7]. They could have been produced in the early Universe. Charged Q-balls should interact with matter in ways not too dissimilar from those of nuclearites.

After a short description of the apparatus, we present the calibrations, the analysis procedures and the results from the SLIM experiment.

2 Experimental procedure

The SLIM (Search for LIght magnetic Monopoles) experiment, based on 440 m^2 of Nuclear Track Detectors (NTDs), was deployed at the Chacaltaya High Altitude Laboratory (Bolivia, 5260 m a.s.l.) since 2001 [8].

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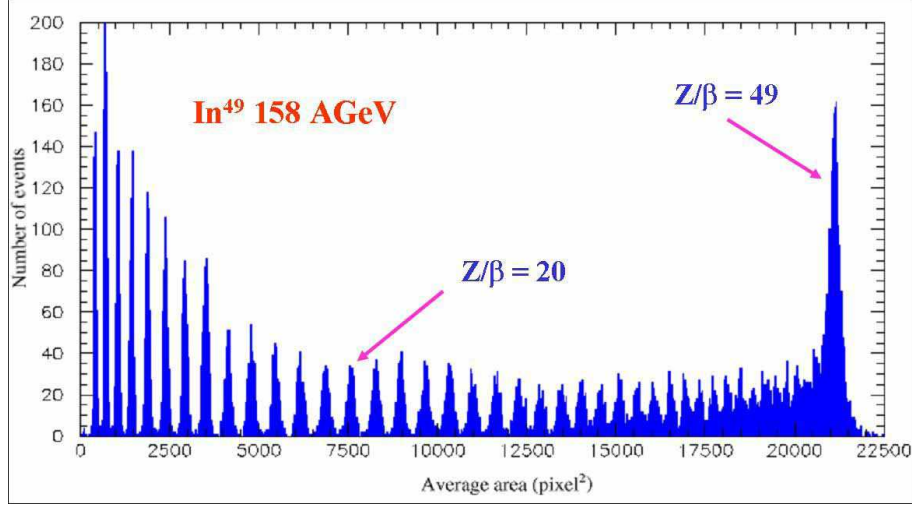


Figure 1: Calibrations of CR39 nuclear track detectors with 158 AGeV In^{49+} ions and their fragments.

The air temperature is recorded 3 times a day. From the observed ranges of temperatures we conclude that no significant time variations occurred in the detector response. The radon activity and the flux of cosmic ray neutrons were measured by us and by other authors [9]. Another 100 m² of NTDs were installed at Koksil (Pakistan, 4600 m a.s.l.) since 2003.

Extensive test studies were made in order to improve the etching procedures of CR39 and Makrofol, improve the scanning and analysis procedures and speed, and keep a good scan efficiency. “Strong” and “soft” etching conditions have been defined [10]. Strong etching conditions (8N KOH + 1.25% Ethyl alcohol at 77 °C for 30 hours) are used for the first CR39 sheet in each module, in order to produce large tracks, easier to detect during scanning. Soft etching conditions (6N NaOH + 1% Ethyl alcohol at 70 °C for 40 hours) are applied to the other CR39 layers in a module, if a candidate track is found in the first layer. It allows more reliable measurements of the Restricted Energy Loss (REL) and of the direction of the incident particle. Makrofol layers are etched in 6N KOH + Ethyl alcohol (20% by volume), at 50 °C.

The detectors have been calibrated using 158 AGeV In^{49+} (see Fig. 1) and 30 AGeV Pb^{82+} beams. For soft etching conditions the threshold in CR39 is at $\text{REL} \sim 50 \text{ MeV cm}^2 \text{ g}^{-1}$; for strong etching the threshold is at $\text{REL} \sim 250 \text{ MeV cm}^2 \text{ g}^{-1}$. Makrofol has a higher threshold ($\text{REL} \sim 2.5 \text{ GeV cm}^2 \text{ g}^{-1}$) [11]. The CR39 allows the detection of IMM with two units Dirac charge in the whole β -range of $4 \cdot 10^{-5} < \beta < 1$. The Makrofol is useful for the detection of fast MMs; nuclearites with $\beta \sim 10^{-3}$ can be detected by both CR39 and Makrofol.

The analysis of a SLIM module starts by etching the top CR39 sheet using strong conditions, reducing its thickness from 1.4 mm to ~ 0.6 mm. Since MMs, nuclearites and Q-balls should have a constant REL through the stack, the signal looked for is a hole or a biconical track with the two base-cone areas equal within the experimental uncertainties. The sheets are scanned with a low magnification stereo microscope. Possible candidates are further analyzed with a high magnification microscope. The size of surface tracks is measured on both sides of the sheet. We require the two values to be equal within 3 times the standard deviation of their difference. A track is defined as a “candidate” if the REL and the incidence angles on the front and back sides are equal to within 15%. To confirm the candidate track, the bottom CR39 layer is then etched in soft conditions; an accurate scan under an optical microscope with high magnification is performed in a region of about 0.5 mm around the expected candidate position. If a two-fold coincidence is found the middle layer of the CR39 (and in case of high Z candidate, the Makrofol layer) is analyzed with soft conditions.

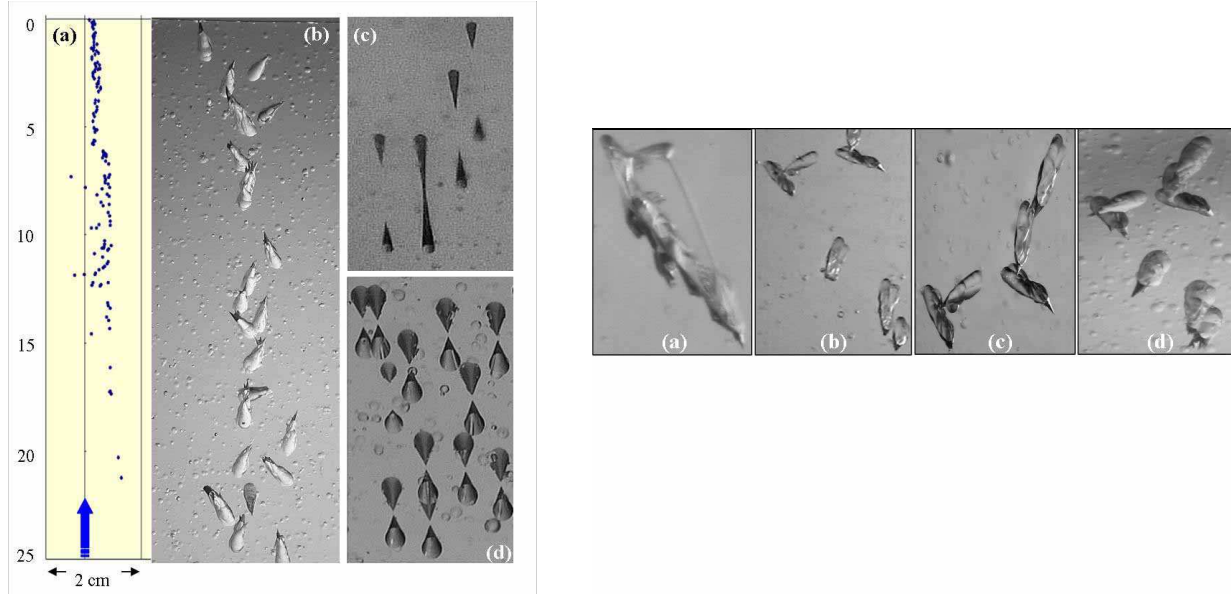


Figure 2: Left: (a) Global view of the “event” tracks in the L1 layer of wagon 7408. (b) Microphotographs of the 22 cones at the top of Fig. 3a. (c) Normal tracks of 158 AGeV Pb⁸²⁺ ions and their fragments (soft etching), and (d) of 400 AMeV Fe²⁶⁺ ions and their fragments (strong etching). Right: Example of “tracks” in the L6 layer of wagon 7410: (a) after 30h of soft etching, (b) after 5h more of strong etching, (c) after 4h more of strong etching and (d) after 10h more of strong etching.

3 Non reproducible candidates

In 2006 the SLIM experiment found a very strange event when analyzing the top CR39 layer of stack 7408. We found a sequence of many “tracks” along a 20 cm line; each of them looked complicated and very different from usual ion tracks, see Fig. 2left(a,b). For comparison Fig. 2left(c) shows “normal” tracks from 158 AGeV Pb⁸²⁺ ions and their fragments and Fig. 2left(d) shows tracks from 400 AMeV Fe²⁶⁺ ions.

Since that “event” was rather peculiar, we made a detailed study of all the sheets of module 7408, and a search for similar events and in general for background tracks in all NTD sheets in the wagons around module 7408 (within a ~ 1 m distance from module 7408). We etched “softly” all the sheets in order to be able to follow the evolution of the etch-pits. A second event was found in the CR39 bottom layer (top face) of module 7410, see Fig. 2right. Some background tracks in other modules were found after 30 h of soft etching. We decided to further etch “strongly” the 7410-L6 layer in short time steps (5h) and to follow the evolution of the “tracks” by systematically making photographs at each etching step. After additional strong etching, the “tracks” began more and more similar to those in the 7408-L1 layer, see Fig. 2right(b,c,d). The presence of this second event/background and its evolution with increasing etching casts stronger doubts on the event interpretation and supports a “background” interpretation also of the “tracks” in module 7408. We made different hypotheses and we checked them with the Intercast Co. Since 1980 we analyzed more than 1000 m² of CR39 using different etching conditions and we have not seen before any of the above mentioned cases. It appears that we may have been hit by an extremely rare manufacturing defect involving 1 m² of CR39.

4 Results and Conclusions

We etched and analyzed 383 m² of CR39, with an average exposure time of ~ 4.07 years. No candidate passed the search criteria: the 90% C.L. upper limits for a downgoing flux of IMMs with $g = g_D, 2g_D, 3g_D$ and for dyons (M+p) are at the level of $\sim 1.5 \cdot 10^{-15} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$ for $\beta \geq 4 \cdot 10^{-2}$, see Fig. 3left. The same sensitivity was reached also for nuclearites with $\beta \geq 10^{-4}$ (Fig. 3right) and Q-balls coming from above

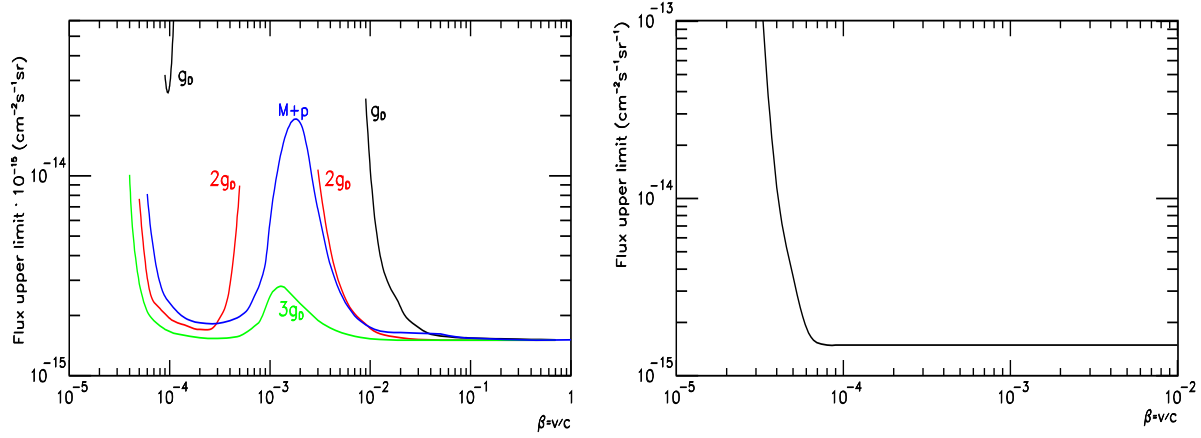


Figure 3: Left: 90% C.L. upper limits for a downgoing flux of IMM fluxes with $g = g_D$, $2g_D$, $3g_D$ and for dyons (M+p) plotted vs β . Right: 90% C.L. upper limits for a downgoing flux of nuclearites with $M_N \leq 8.4 \cdot 10^{14}$ GeV.

with galactic velocities.

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